Conference Summary

2nd TPF/Darwin Conference

Frank H. Shu

National Tsing Hua University

Outline of Talk

- Expression of Gratitude to Chas Beichman, Malcolm Fridlund, & Steve Unwin
- "Building a Community" (Chas Beichman)
- Science Topics
  - Planet Detection: Present Status
  - Planet Formation: Theory
  - Constraints from Chemistry, Geochemistry, Grain Mineralogy & Growth
  - Disappearance of Inner Disks of YSOs
  - Debris Disks
  - Chronometers
  - Thinking Out of the Box
  - Conservative & Aggressive Habitat Chartion
- Building TPF/Darwin (not competent to review)
  - **Ken Johnston, Malcolm Fridlund, Wes Traub, John Trauger, David Leisawitz**

“Building a Community” Under a Big Tent

- Comment of former Vice-Chancellor of Cambridge, David Williams.
- Instrumentalists, astrophysicists, astrochemists, astrobiologists, planetary scientists, geophysicists, geochemists.
- Good counterweight in astronomy:
  - Cosmology: sensitivity (“ever more glass”)
  - Exo-planets: angular and spectral resolution

Planet Detections: Present Status

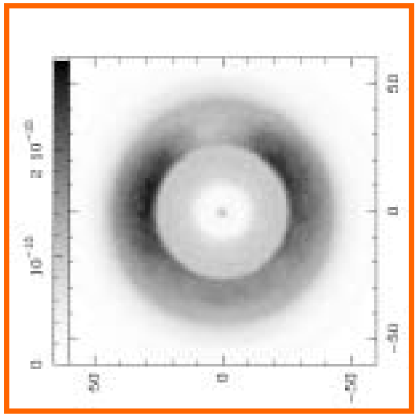
•Method	•# det	•Follow-up	•a	•M_J
•Pulsar Timing	•3		•~0.4	•~0.01 - 0.0001
•Doppler Spec	•119	•conf	•~0.04 - 4	•~0.1 - 10
•Astrometry		•conf		
•Transit Phot	•3	•conf	•~0.03	•~1
•Microlensing	•1		•~3	•~2
•Reflected Light*		•limits		
•Direct Imaging				

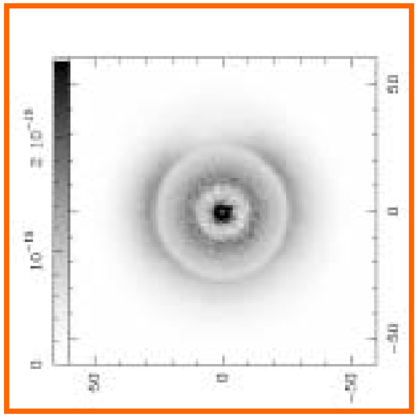
*Including polarimetry (**Daphne Stam**)

Penny Sackett

Planet Detection: Inferences for Planets

Question: Can dust distribution features indicate planets (via resonant or secular interactions)?



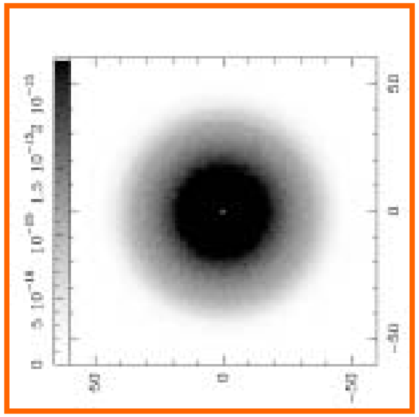


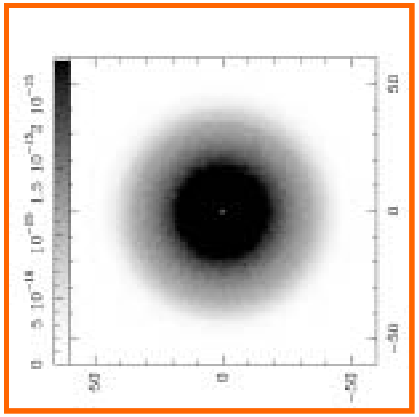
70 microns

Dust avoids Neptune. Gravitational scattering by Jupiter and Saturn keeps most KBO dust from entering to < 10 AU.

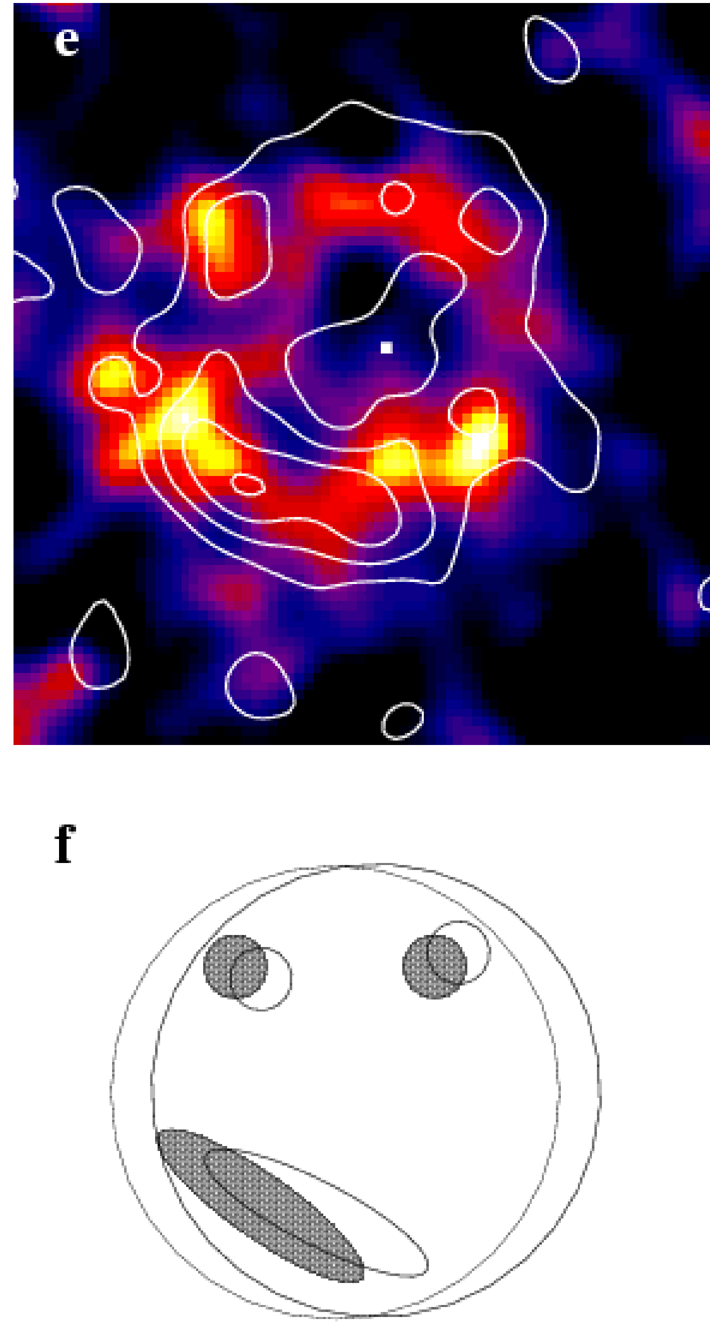
24 microns

Amaya Moro-Martin





- Ring rotation??
  - Tentative evidence inεEridani debris disk of counter-clockwise rotation at 1-2° per year?
  - Spitzer quoting Eddington: “Never believe an observation until it has been confirmed by theory.”



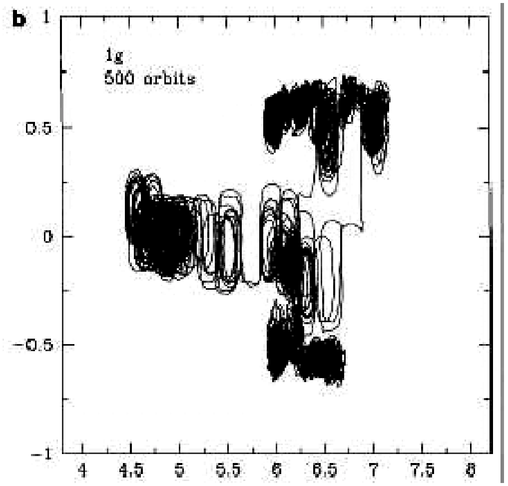
Jane Greaves, Mark Wyatt, Pawel Artymowicz

Planet Formation: Theory

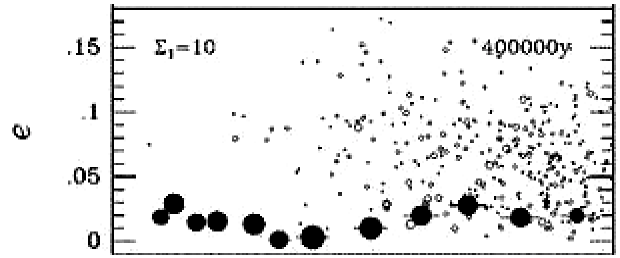
Victor Safronov:

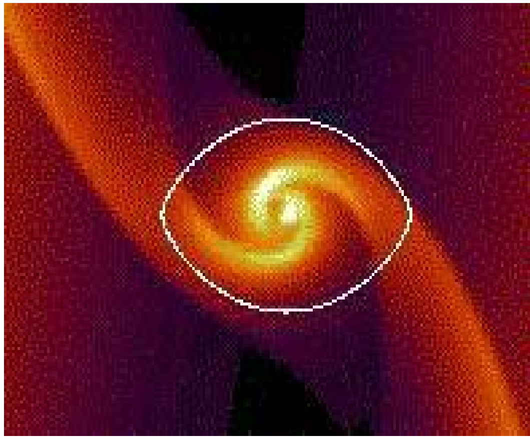
"There are only two kinds of self-gravitating objects in the universe: spheres and disks."

Star and planet formation is largely about the way disks make spheres. Just how this happens is the **Great Debate**.



Sequential Accretion of gas giant planets





Requirements:

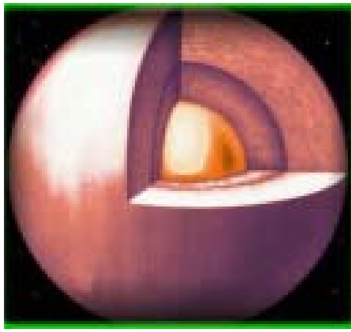
1) Heavy element retention
2) Rapid growth of massive cores
3) Termination of gas accretion

Advantages:

1) Heavy elements' enhancement
2) Core structure
3) Mass & dynamical distributions

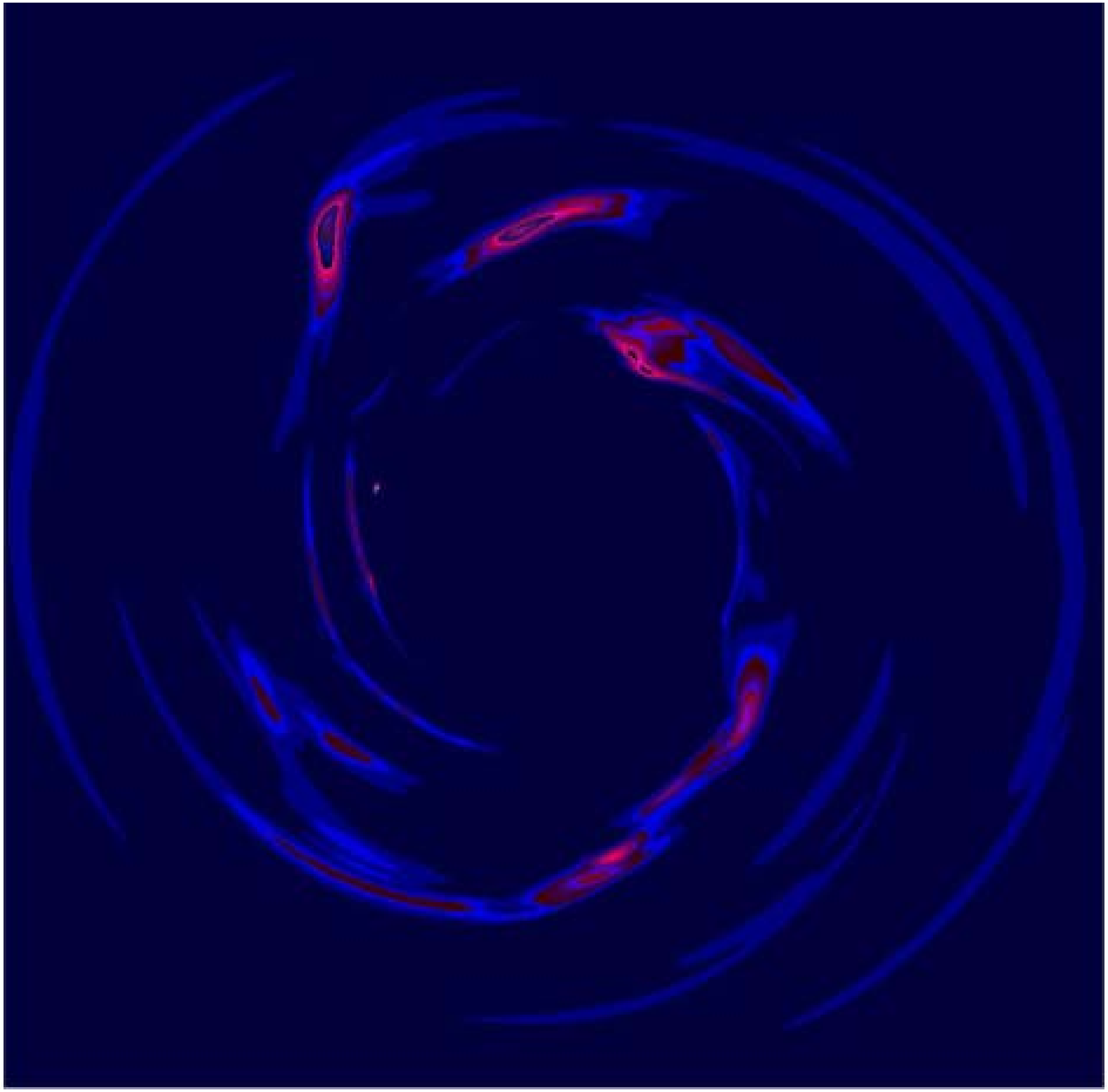
Outstanding issues:

1) Formation time scale; 2) Jupiter's small-core structure;
3) Planet in metal-deficient M4; & 4) Dynamical diversity



Doug Lin

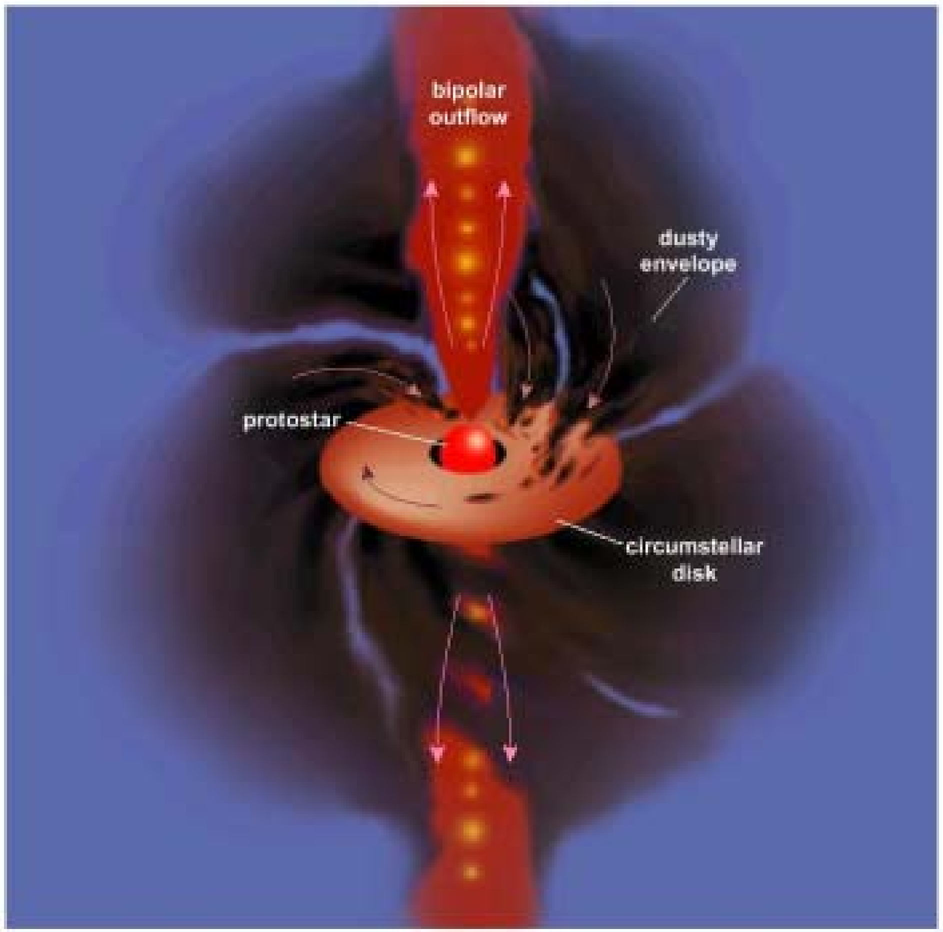
Boss 2003 disk instability model after 429 yrs, 30 AU radius



May be marginally resolvable with VLA-Pie Town, SMA, & CARMA. ALMA will put GI to the test (**Anneila Sargent, David Wilner**).

Currently, unknown amount of gas in early stages (**Alexis Brandeker**). All exisitng “disk-mass” estimates assume a dust cross-section for mm-waves and a gas-to-dust ratio (**Jens Rodmann**).

But Disks Are Not Put into Place in An Initially Unstable State



It is conventionally believed that when disk and star are built up progressively, spiral density-waves and/or bars appear that exert sufficient gravitational torque to stabilize the system against internal fragmentation. However, this belief is not based on honest calculation, and it may fail when turbulence and magnetic fields are introduced realistically. On the other hand, if binaries and giant planets both form by a fragmentation process, the companion BD desert would become a mystery.

Neal Evans

Other Mechanistic Problems

- Core-Accretion Scenario:
  - Source of viscosity for disk accretion (MRI dead zones)
  - Difficulty of getting from dust to planetesimals (100 m/s)
  - Fast migration by interaction with gas disk (bad thing)
  - Slow migration by interaction with particulate disk (good thing, **Renu Malholtra**)
- Gravitational Instability Scenario:
  - Photoevaporation of gas giant (Jupiter) to ice giant (Uranus or Neptune) by external irradiation of UV

$$R_s = \frac{GM_p}{2{c_s}^2} = R_E \left(\frac{M_p}{M_E}\right)\left(\frac{5.5\text{ km/s}}{c_s}\right)^2 = 10^3 R_E \text{ if } M_p = M_J \text{ and } c_s = 3\text{ km/s.}$$

$$\dot{M}_p = 4\pi {R_s}^2 \rho_s c_s \text{ where } \rho_s \approx \rho(R_p) e^{-GM_p/R_p c_s^2} = \rho(R_p) e^{-2R_s/R_p}.$$

  - Highly optimistic case:

$$R_p \approx R_s,\ \rho(R_p) \approx \rho_n \Rightarrow \dot{M}_p \approx 2\dot{M}_n \left(\frac{R_s}{R_n}\right)^2 \approx 2\times(10^{-7} M_S/\text{yr})\times 10^{-4} \approx 2\times 10^{-8} M_J/\text{yr}.$$

  - Still not enough to strip a Jupiter into a Neptune
- Compromise: Use GI to form (first) Jupiter to open gap and slow down fast gas-migration of other outer planets that then form by core-accretion?

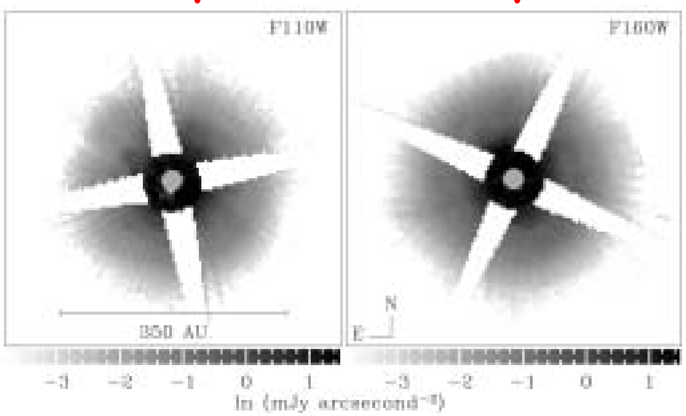
Constraints from Chemistry, Geochemistry, Grain Growth & Cystallization

- How does disk accretion work?
  - Gravitational torques from spiral waves? Planet torques?
  - MRI: ALMA maps of ionization fractions in protoplanetary disks
- Are there solids intermediate in size to chondrules (mm)/CAIs (cm) and planetesimals (km) in protoplanetary disks? Thrown out by X-wind?
- YSO jets/winds dusty? If so, do they carry crystalline silicates with them?
- Connection between cystallization of grains, growth to mm-cm sizes, and overall volatile depletion pattern of meteorites and terrestrial planets (see talks of **Waters, Wilner, Rodmann, Weinberger, Taylor**)?
- Note such a picture automatically couples above time scales to gas accretion time onto central star. Otherwise coincidence of ~ Myr for all four is somewhat mysterious.

Detection of DCO$^+$ in the TW Hya disk (Ewine van Dishoeck)

TW Hya face-on disk

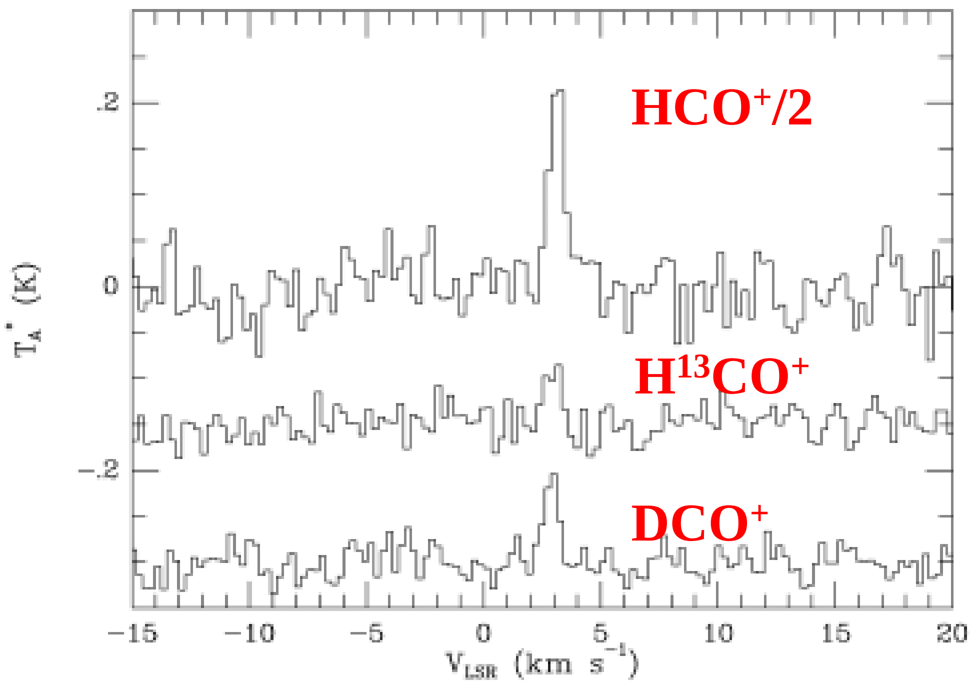
1.1 µm 1.6 µm



Scattered light => radius 200 AU

Weinberger et al. 2002

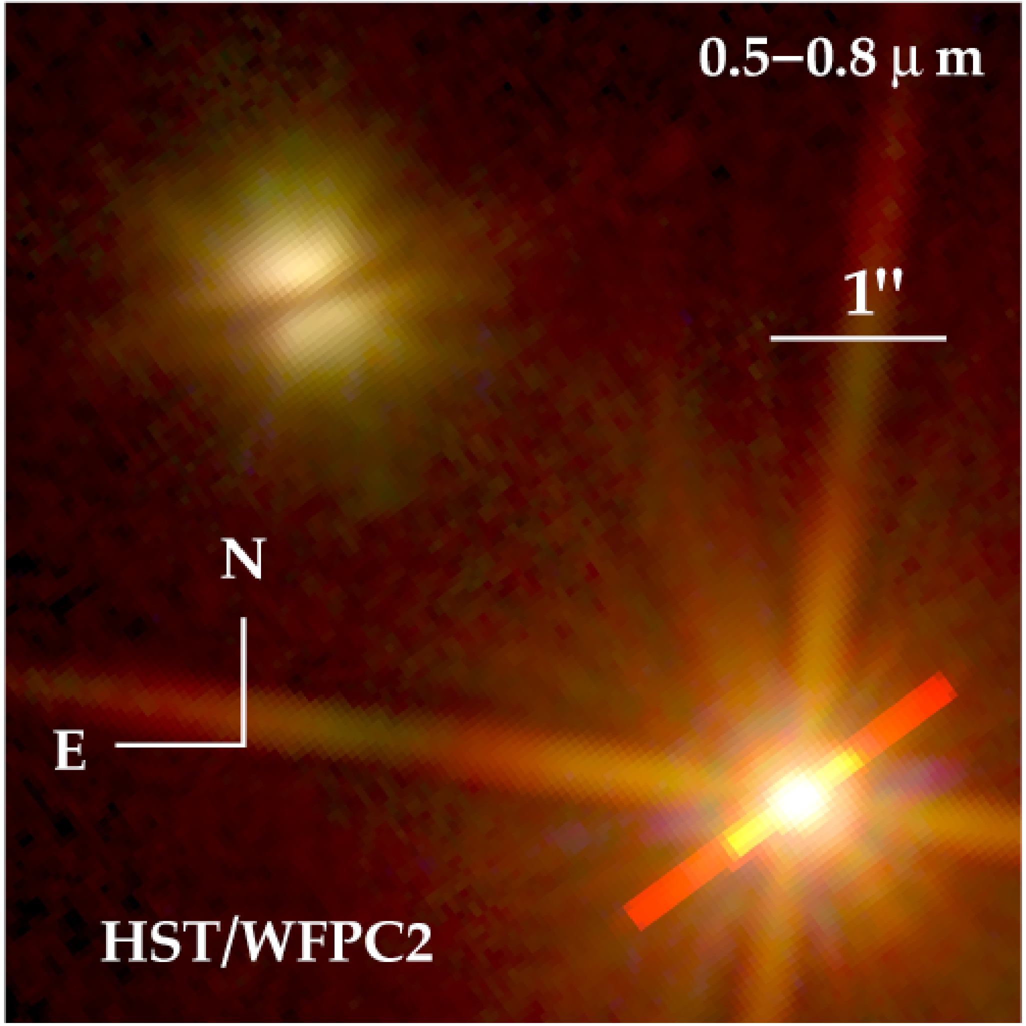
JCMT



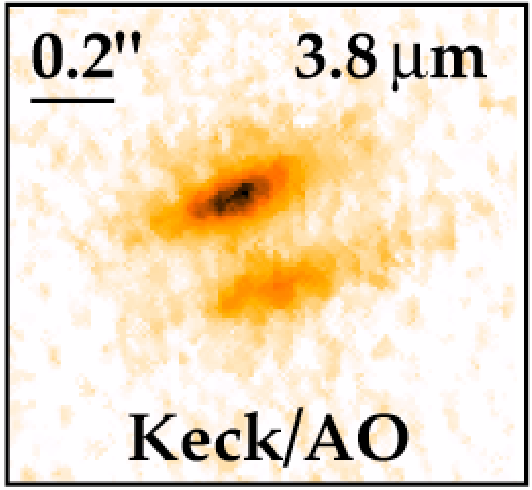
van Dishoeck et al. 2003

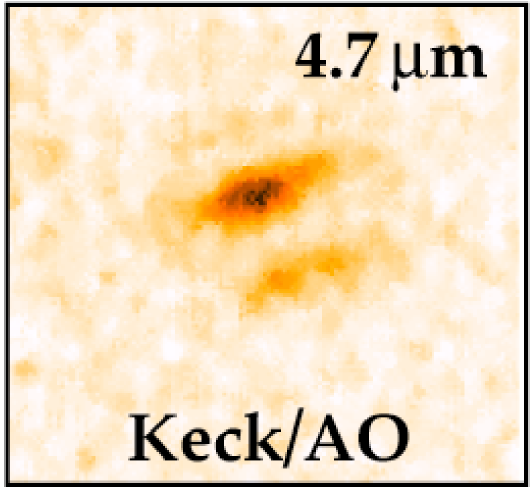
- DCO$^+$/HCO$^+$=0.035 => emission arises from layer with heavy depletions
- Level of deuterium fractionation comparable with that found in cold pre-stellar cores and comets
- HCO$^+$ abundance few x 10^{-11} – 10^{-10} => lower limit on ionization fraction

Space/AO Imaging of HV Tau



Stapelfeldt et al 2003

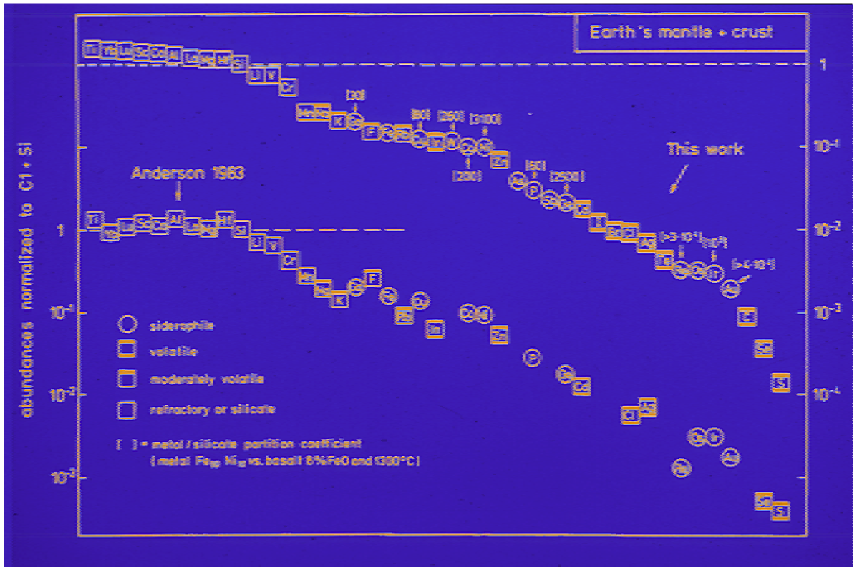




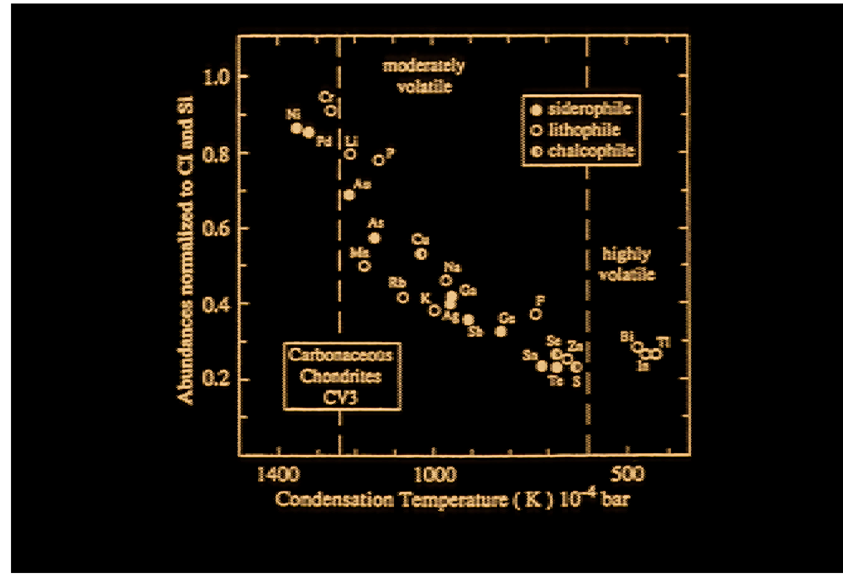
Courtesy of G. Duchene

Glenn Schneider

Elemental depletions, relative to CI, in the Earth correlate with volatility



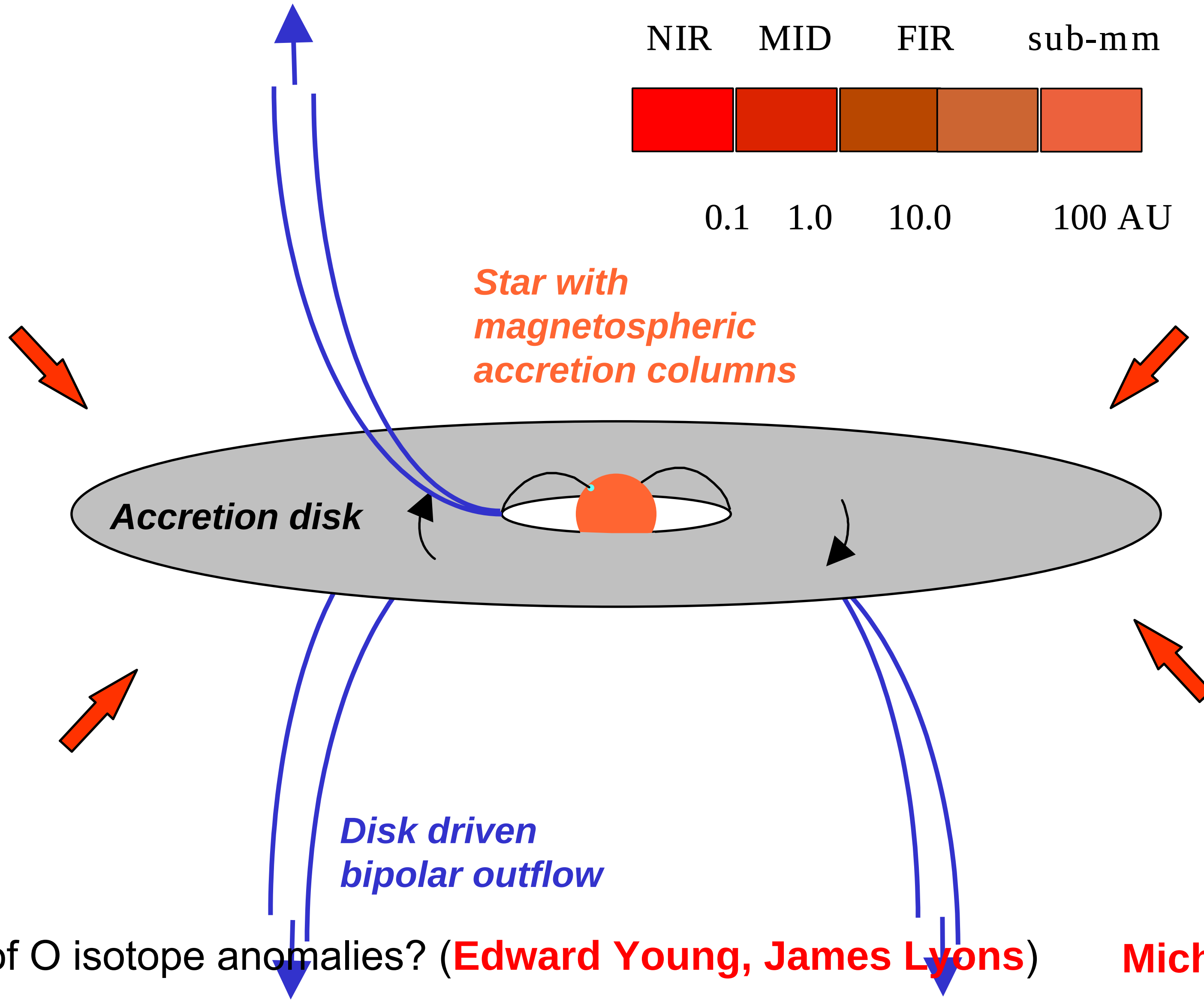
Wänke



Palme

Ross Taylor

Different Wavelengths Trace Different Radii!

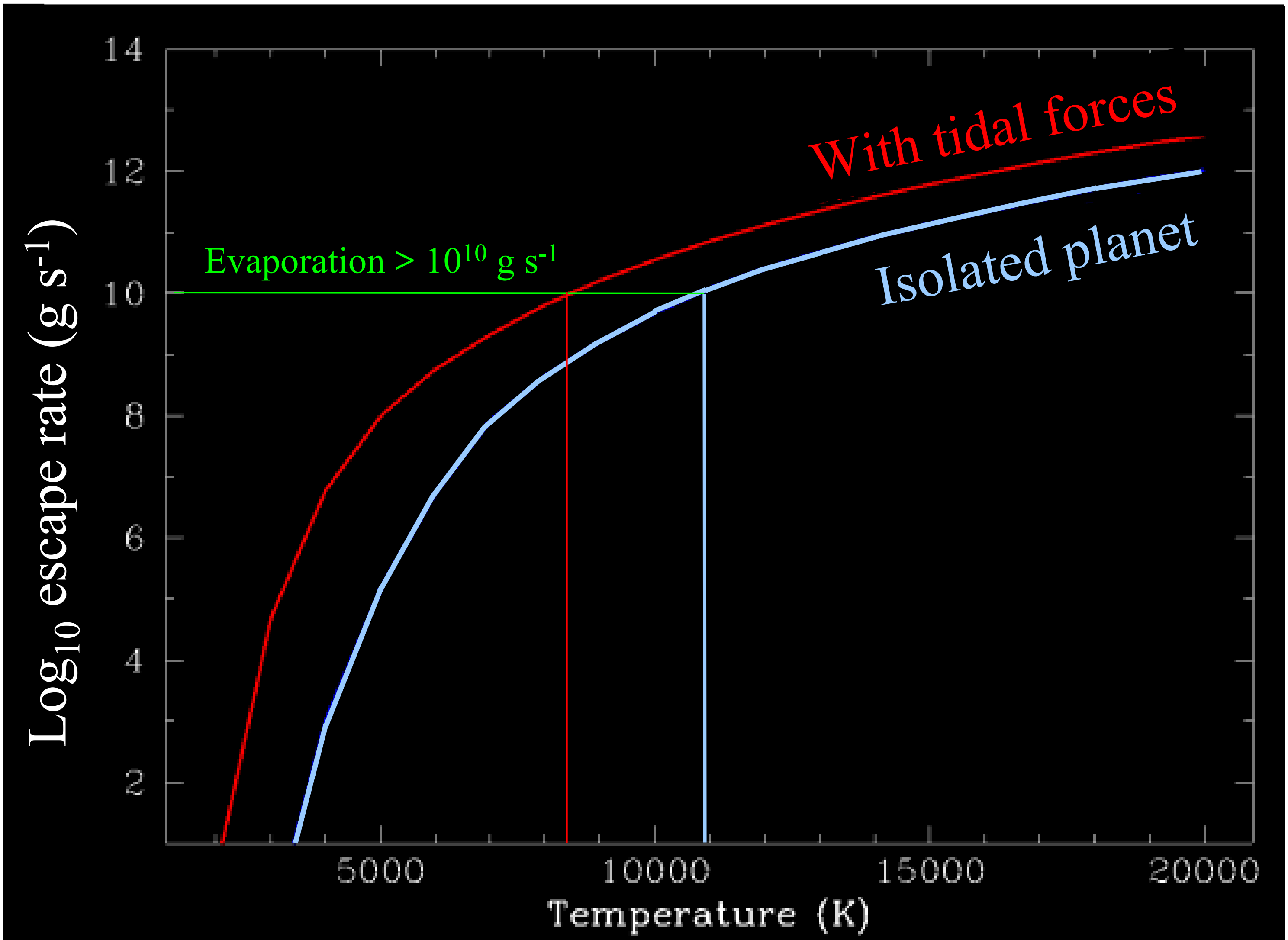


Origin of O isotope anomalies? (**Edward Young, James Lyons**) **Michael Meyer**

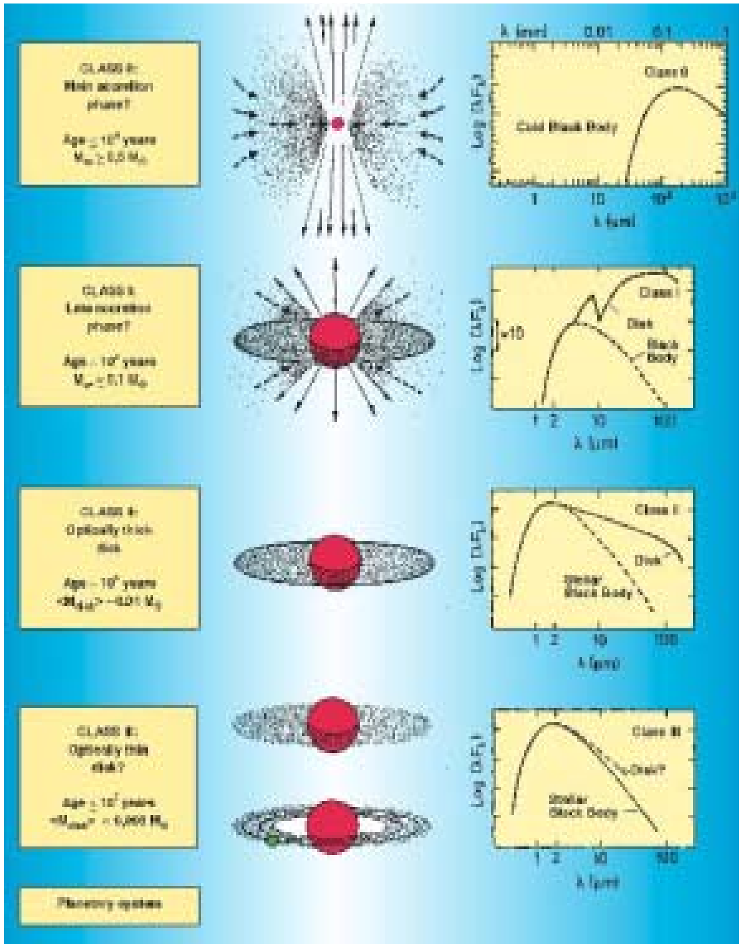
Hot Jupiters

Pile-up of hot Jupiters at 3-4 day periods implies that inner-edge of gas disk at 6-8 day, or about 0.05 AU in CTTSs. This is roughly 3 times smaller than **Rachel Akeson** et al.'s determination of inner-edges of dust disks.

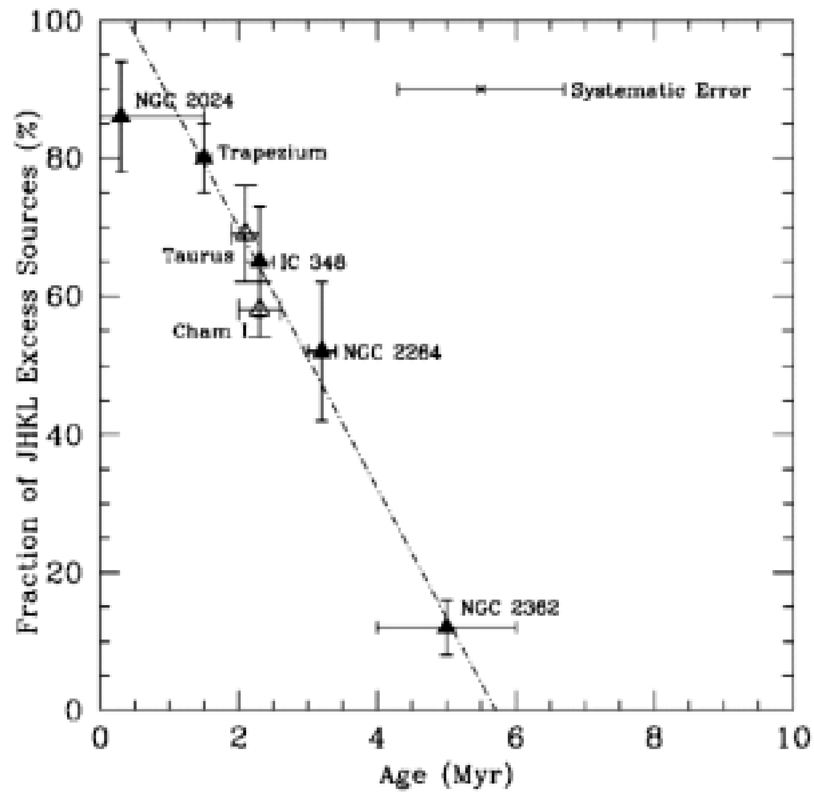
Mass Evaopration Rate
(Lecavelier et al., 2004, A&A 418, L1)



Disappearance of Inner Disks of YSOs



Haisch, Lada & Lada 2001, ApJ 553:L153



Deborah Padgett

Alexis Brandeker

Origin of the central clearing in the CoKu Tau/4 disk (continued)

- Compact companion in orbit within clearing, holding back outer disk with orbital resonances and allowing accretion of inner disk on viscous timescale?
  - Stellar companion? **Probably not:** no sign of a star in the system besides the M1.5 star.
  - Rocky planets? **No:** Hill sphere too small, migration would set in too fast.
  - Giant planet(s) or brown dwarf(s)? **Yes!**
- And, indeed, simulations bear this out (Quillen *et al.* 2004, ApJL, in press, at right). Parameters: 0.1 Jupiter mass planet, disk density aspect ratio is h/r = 0.05, Reynolds number $R = 10^5$.
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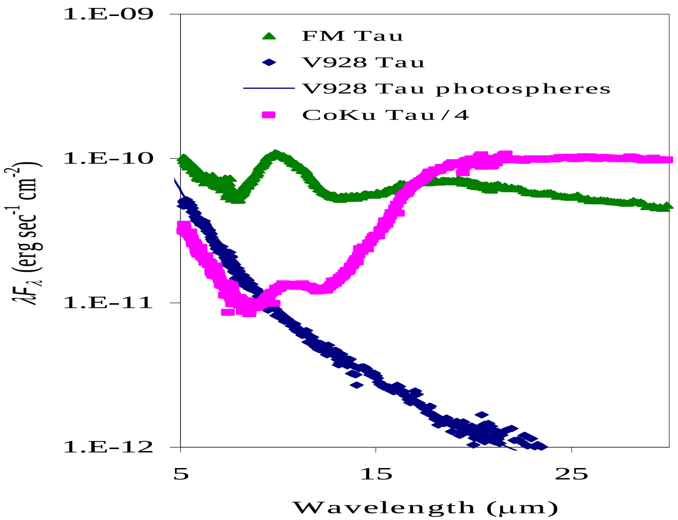
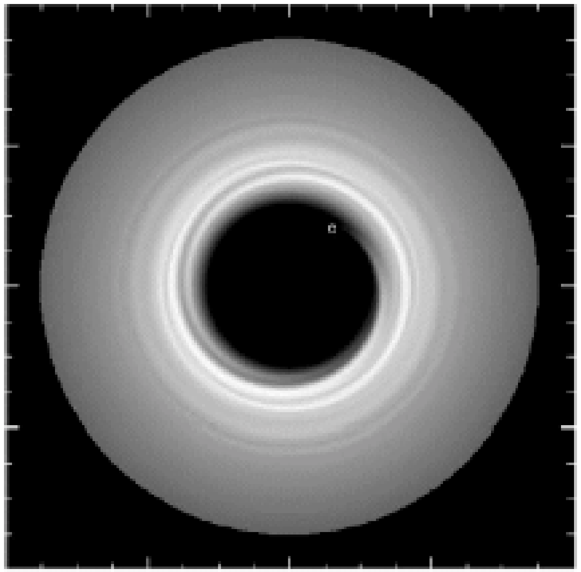
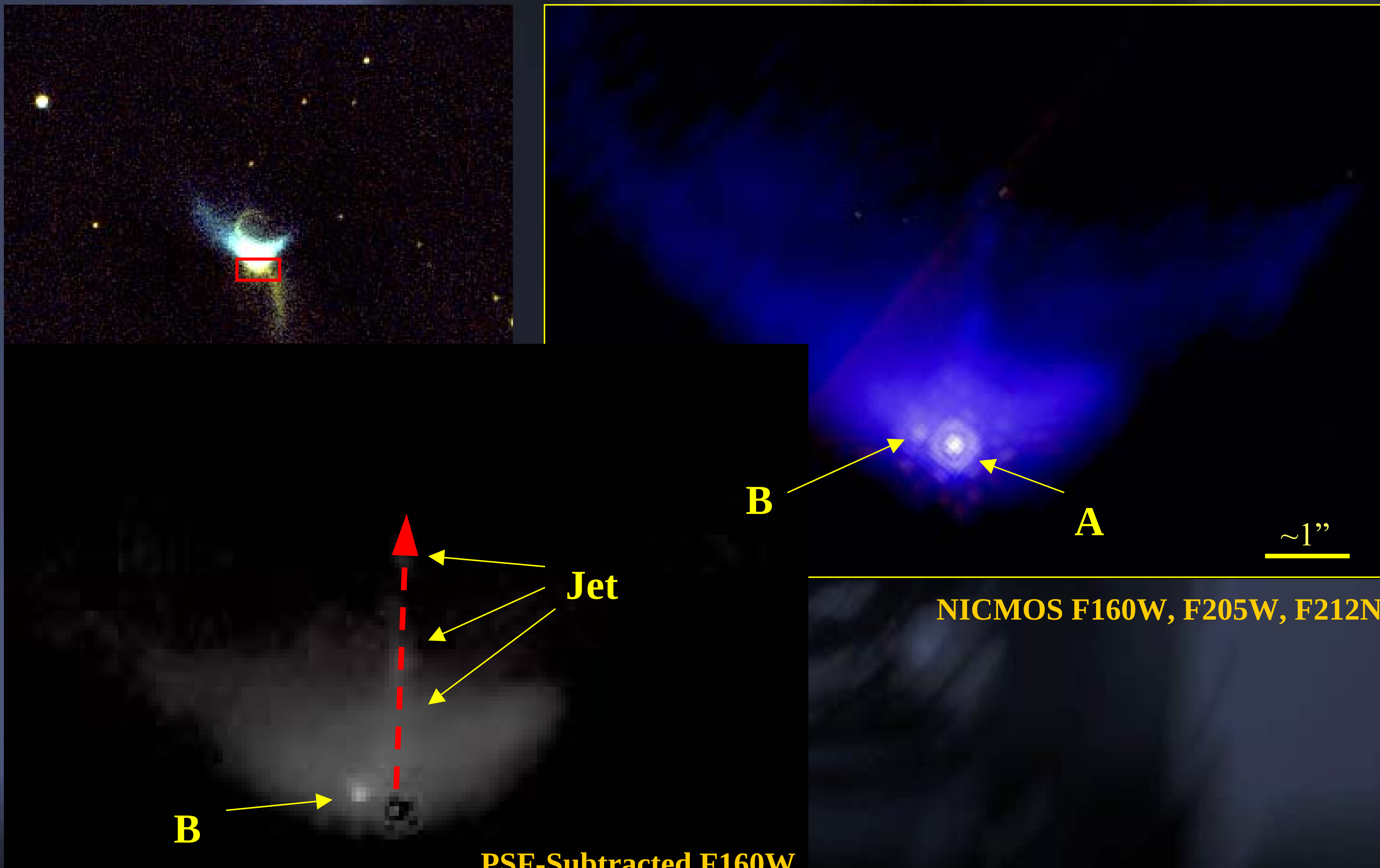
Learn more in the poster by Bill Forrest *et al.*, on display now.





Dan Watson

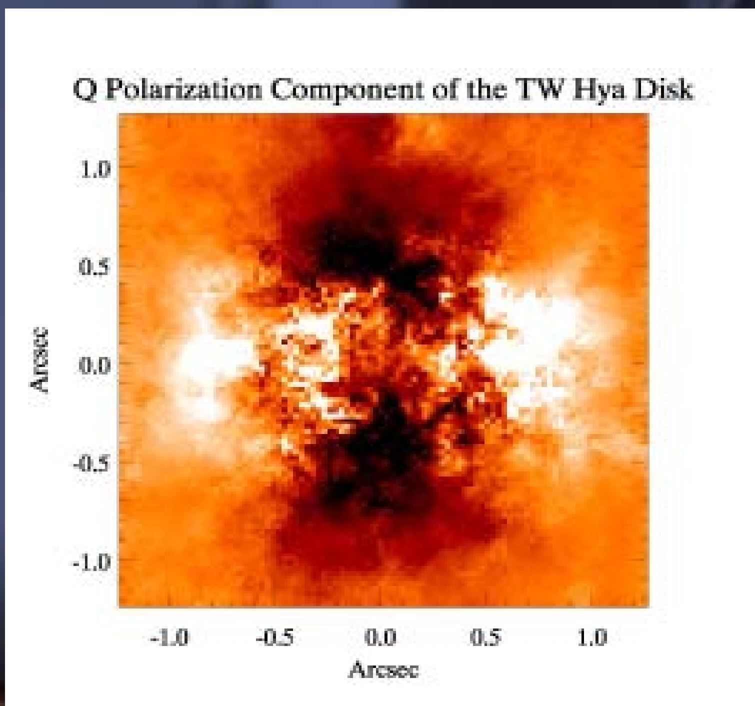
Taurus Molecular Cloud

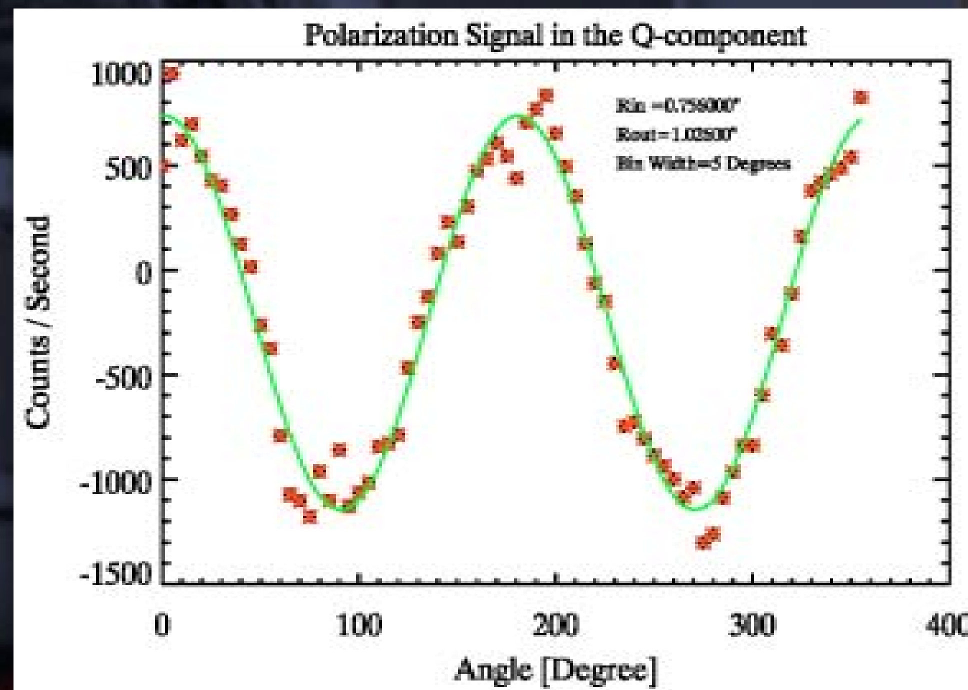


D. Apai

NACO DPI Results on TW Hya

Strong Polarization signal between 0.5” and 1.4” :





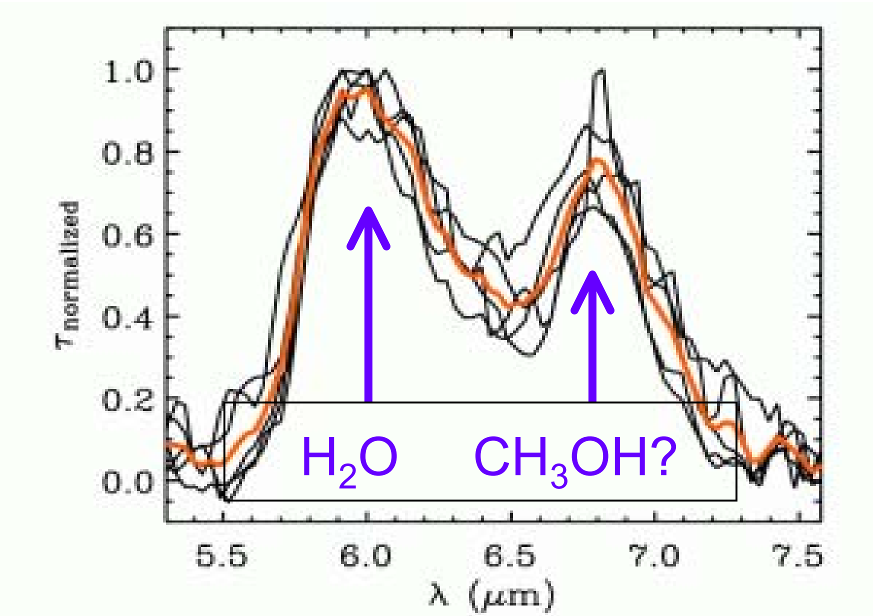
More high-resolution images to come: **Tom Herbst** & this **morning’s speakers,**

VLT-I (**Bruno Lopez**) , Nulling Survey Herbig AeBe (**Phil Hinz**),

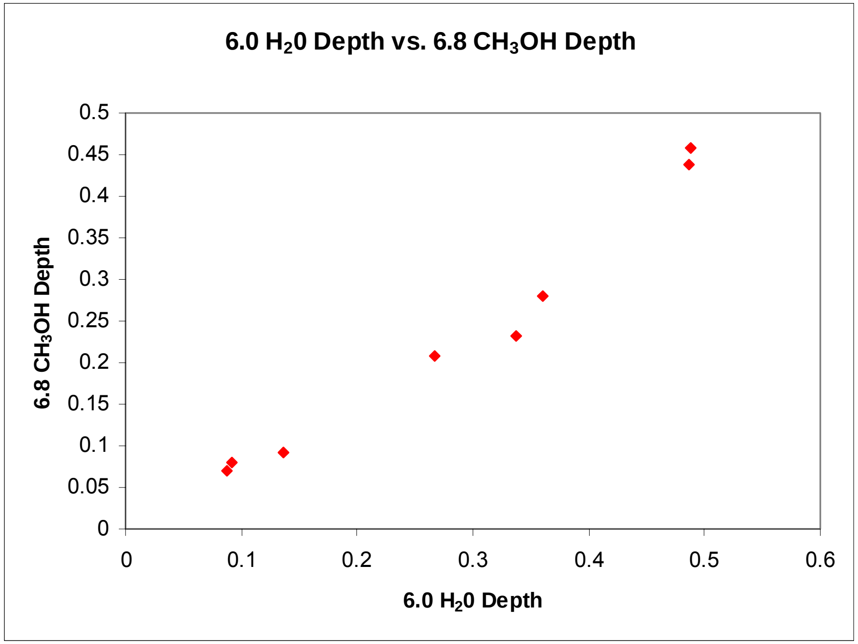
Pegase (**Oliver Absil**), Closure Phase (**John Monnier**).

D. Apai

Where Does Snowline Lie (Ciska Kemper)? Does it Move (Marc Kuchner)?



Correlation between 6.0 and 6.8 is very tight



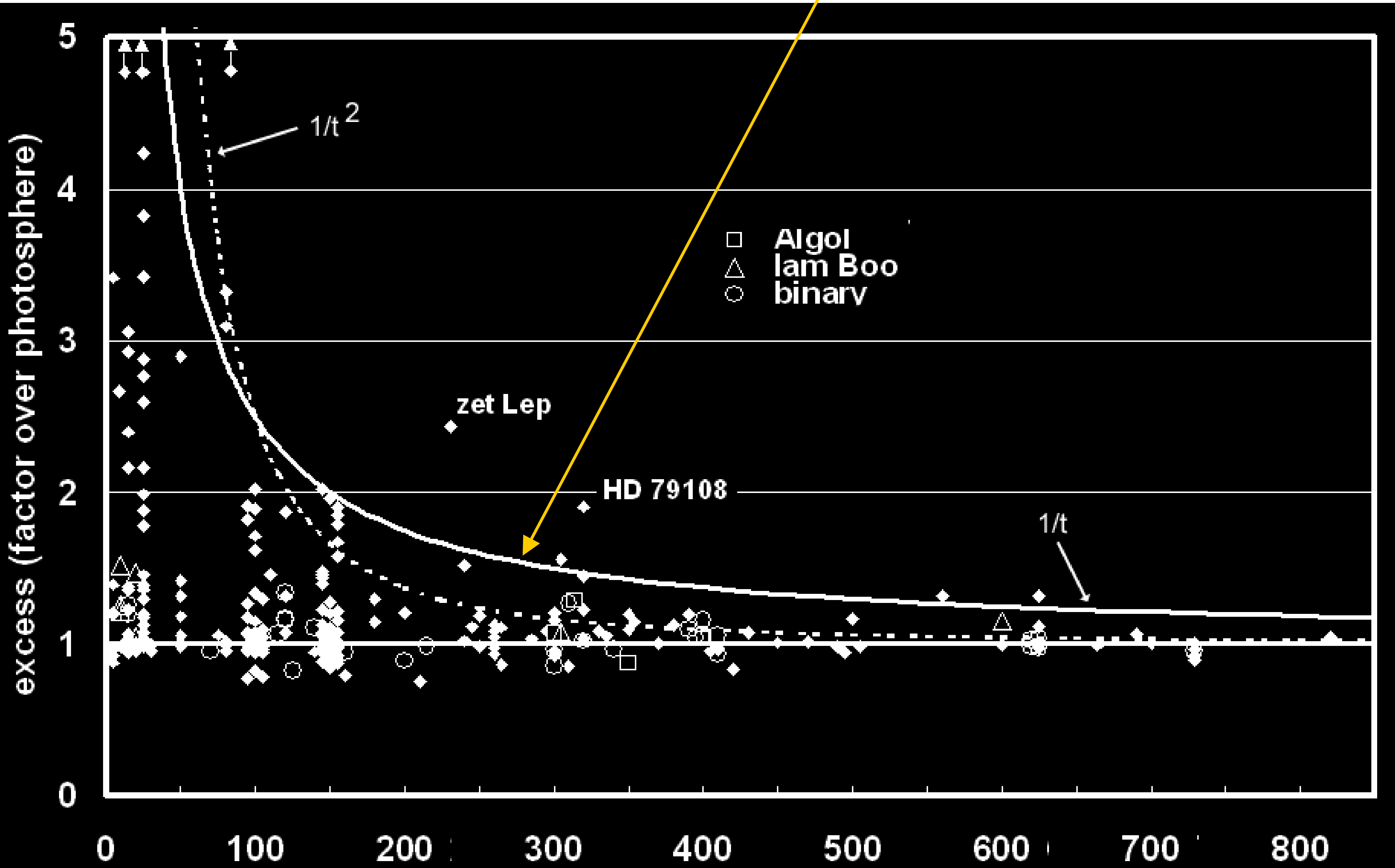
Do all class I sources have the same H_2O:CH_3OH ratio?

Importance for Jupiter & life on Earth (**Jonathan Lunine**)

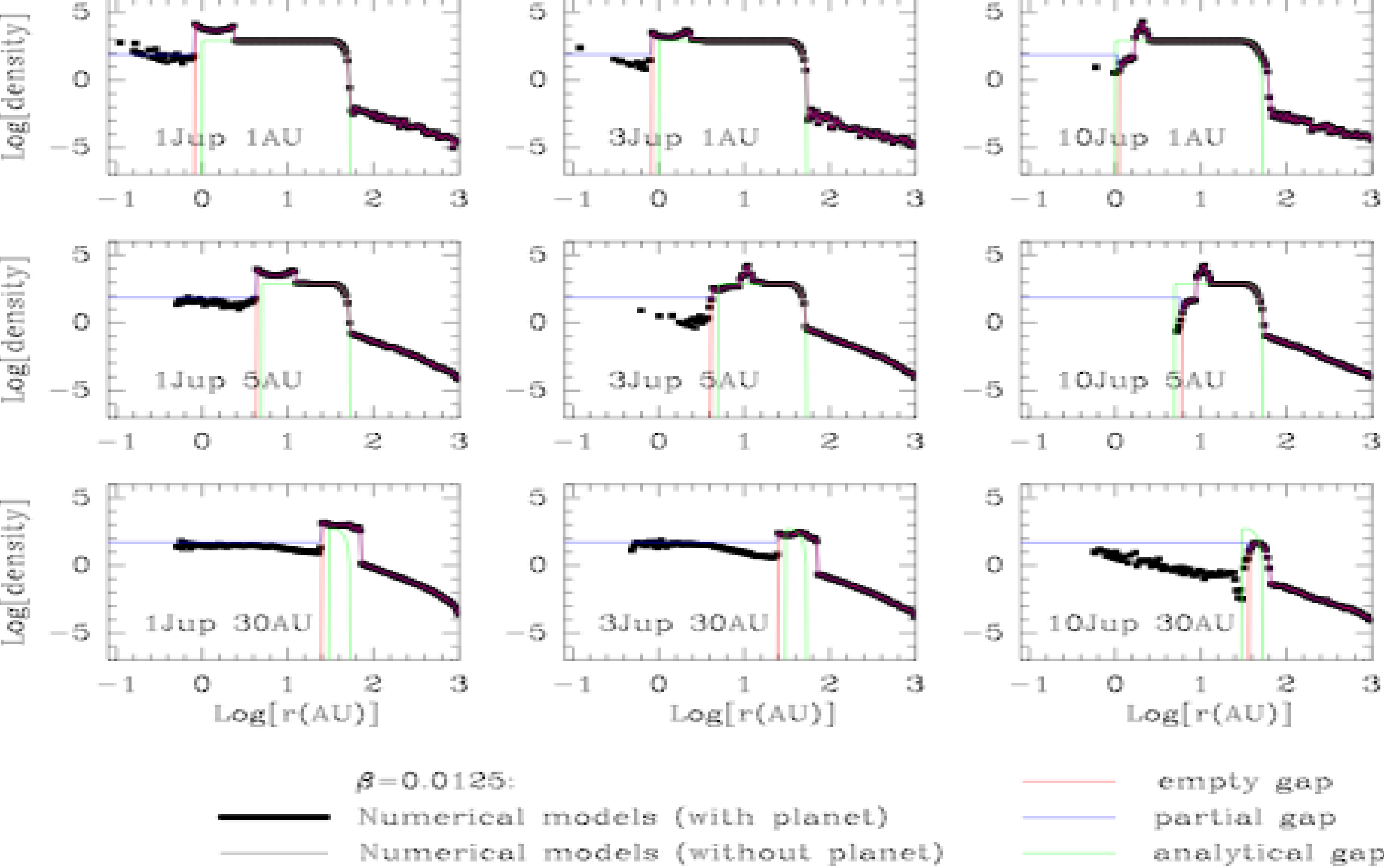
Debris Disks

- Central concern for TPF/Darwin

Upper envelope consistent with 1/t decay (Dominik & Decin, Kenyon & Bromley)



Lower limit could be 1 (**Dana Backman**) age (MYr) **George Rieke**

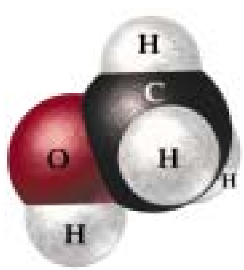


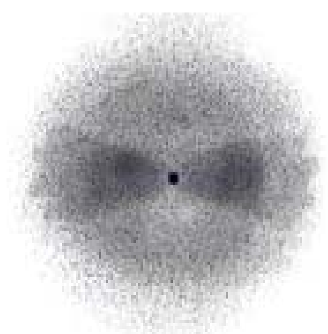
Moro-Martin 2004 Ph.D. thesis, U. Arizona

Dana Backman

Oort Cloud

- We report the first mm wave detection of a complex organic molecule in the outer part of a protostellar disk
- Methanol emission is seen in two condensations located ~ 10,000 AU on either side of the central star forming disk, appearing as an shell
- The methanol is cold (T_{kin} ~ 6 – 10K), dense ($N(H_2) \sim 10^4$ cm^{-3}), unexpectedly abundant (X = > 2 x 10^{-8}), and has a column density ~ 2 x 10^{13} cm^{-2}. at 10,000 AU
- Chemical models can not support such high methanol abundances resulting from gas phase reactions, and require a way of returning gas from the central core to the outer disk – most likely by desorption from the surface of a flared disk – heated by one of a number of potential energy sources close to the L1551 protostellar binary system
- The methanol will deplete onto grain surfaces in $\leq 10^5$ years, becoming assimilated onto dust grains, and freezing information about the nebular abundances in the outer icy bodies
- The outer envelope dust grains aggregate, forming icy outer disk L1551 bodies such as comets – the precursor material to the L1551 Oort cloud – the beginning of chemical complexity





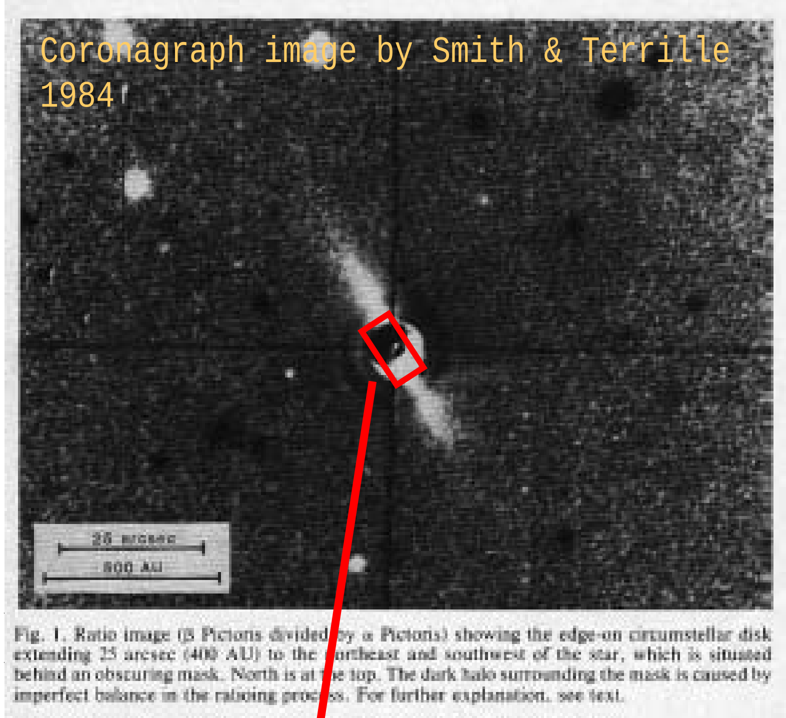
Glenn White

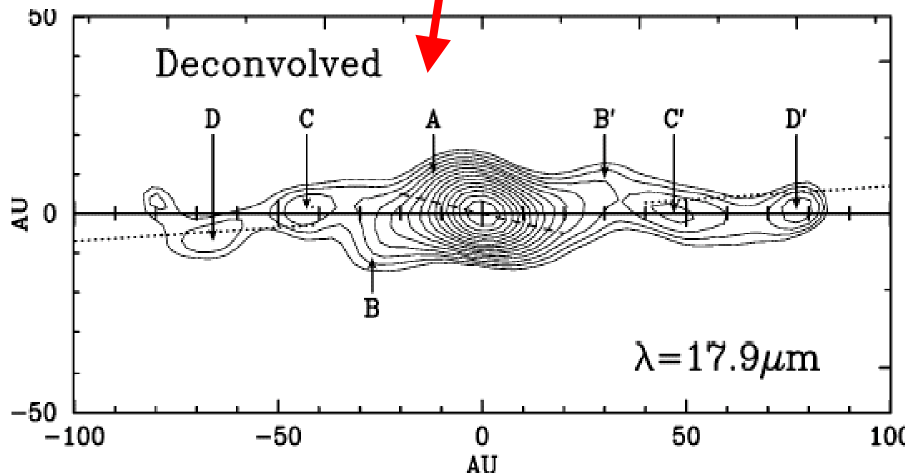
β Pic

- The most investigated Vega-like star
  - An A5V star with an edge-on disk
  - Amorphous and crystalline silicate (Knacke et al. 1993)
  - Indirect evidences for a planetary system
  - Age~20Myr, D=19.28pc (Crifo et al. 1997; Barrado y Navascues et al.1999
- Mid-IR observations are powerful to investigate
  - The inner disk structures
    - planet forming region

      inside the EK belt (r<50AU)
  - Disk dust composition.
    - Silicate crystallization
- 18μm dust rings
  - What are these dust?
    - Structures related to the planetary system formation?

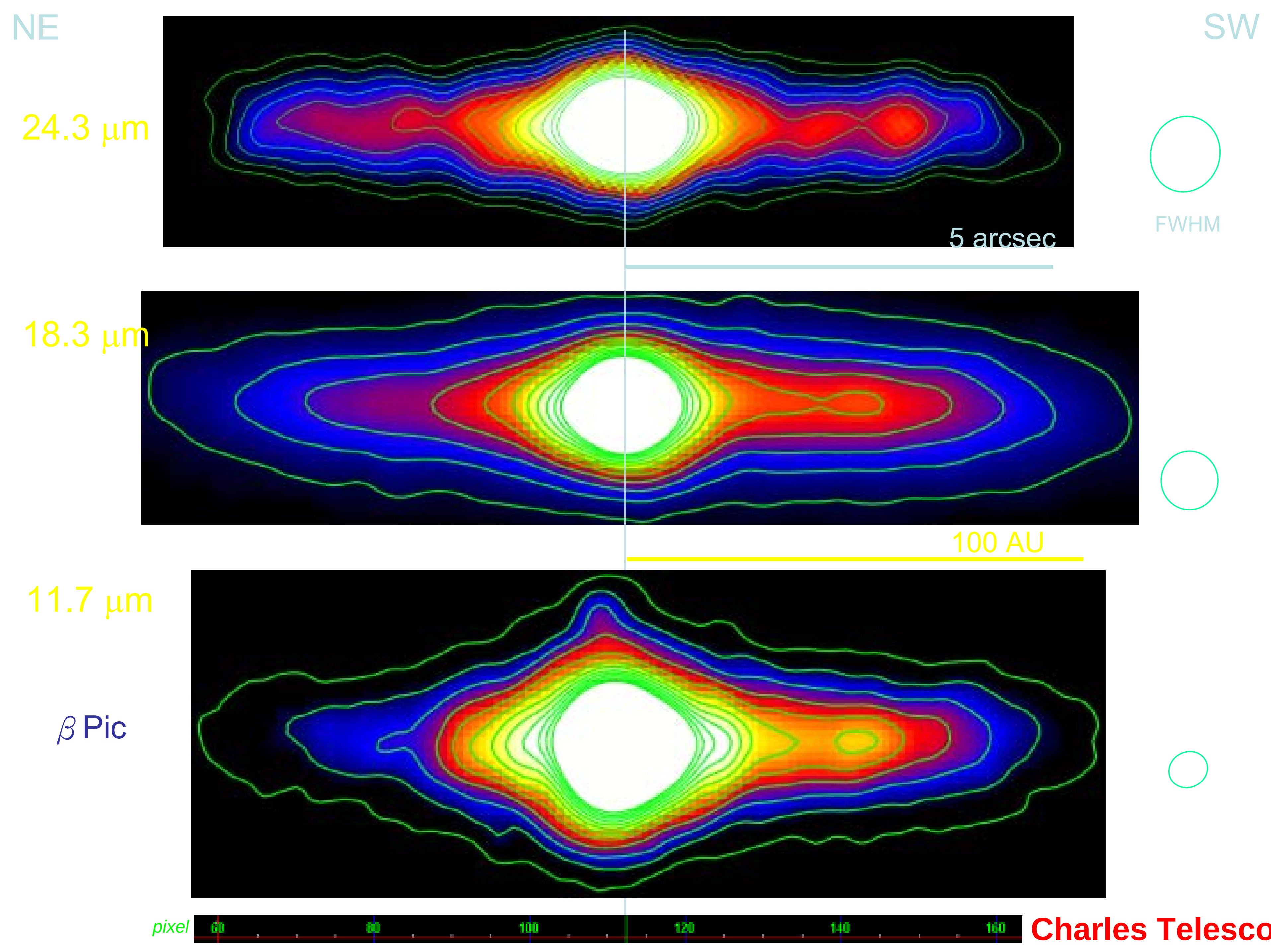
->N-band spectroscopy resolving the disk





Inner dust rings revealed from the deconvolved 17.9mm image by Wahhaj et al.2003 (A-D @ 14, 28, 52, 82AU)

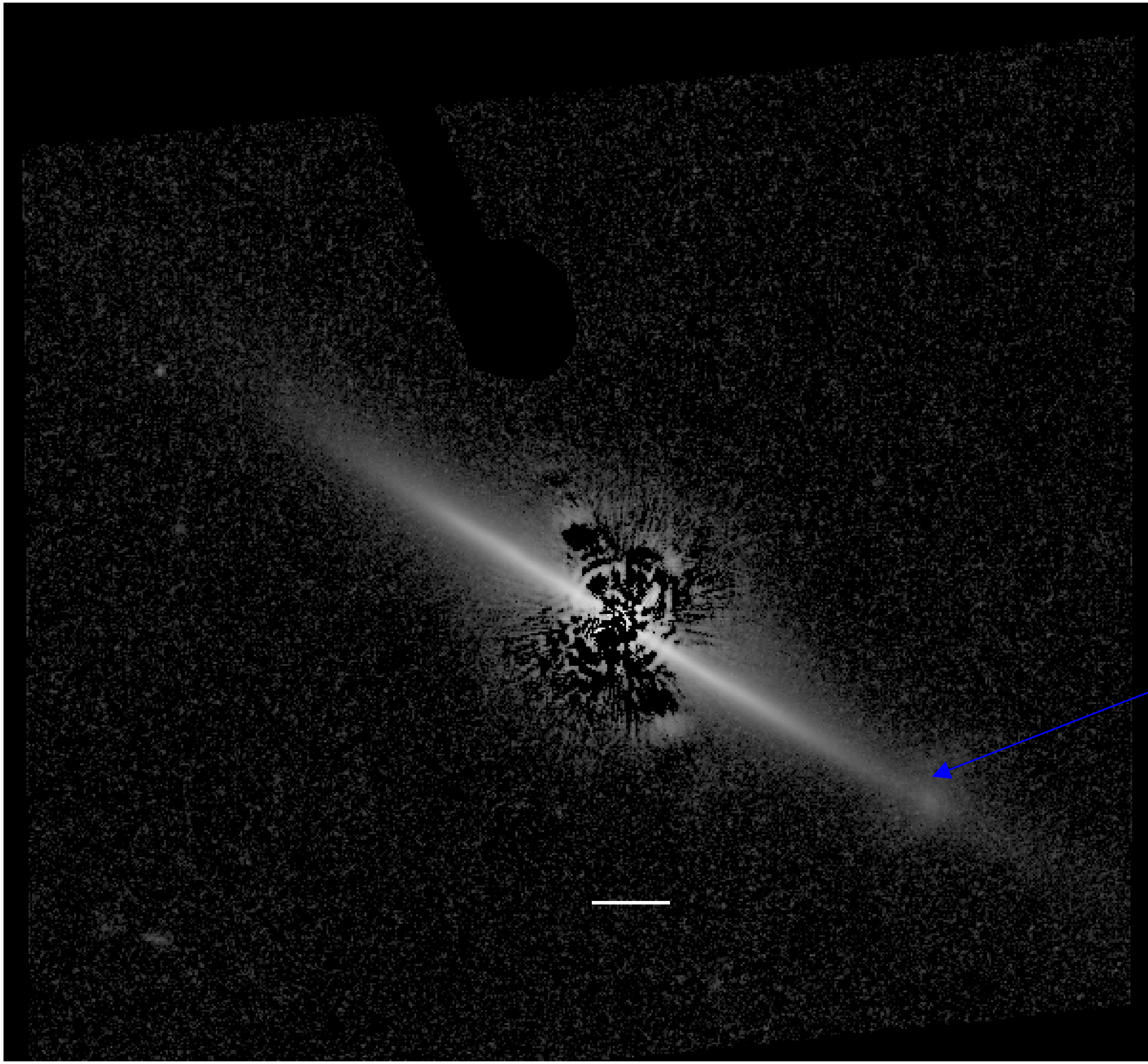
Yoshiko Okamoto



NE
SW
24.3 μm
FWHM
5 arcsec
18.3 μm
100 AU
11.7 μm
β Pic
pixel
60
80
100
120
140
160
Charles Telesco

AU Mic Reference PSF subtracted

John Krist



Why does debris disk flare where it does? Is this where $1/\Omega\tau$ exceeds age of the system?

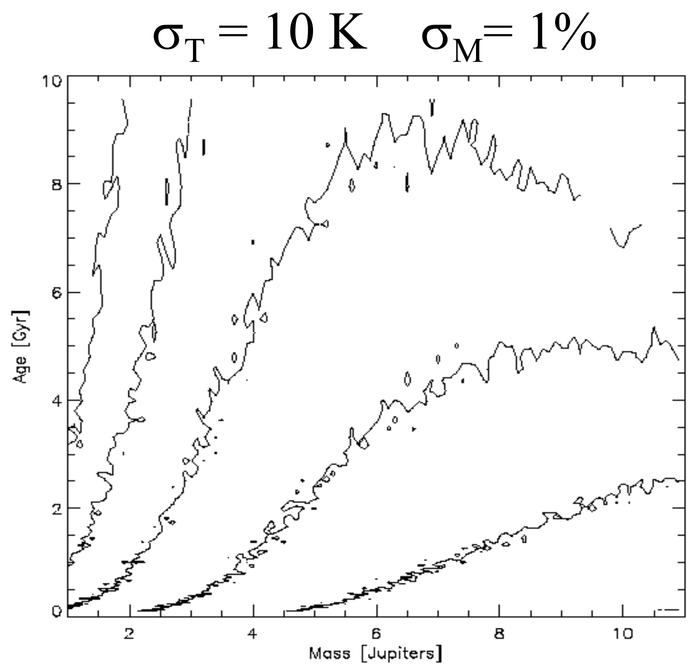
Background galaxy

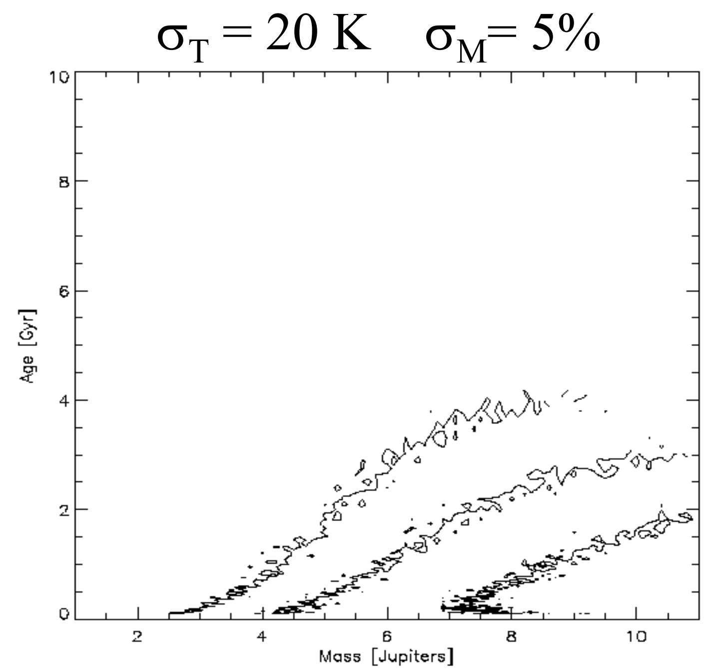
For more information on AU Mic, see talks of **Michael Liu, Paul Kalas, Aki Roberge**)

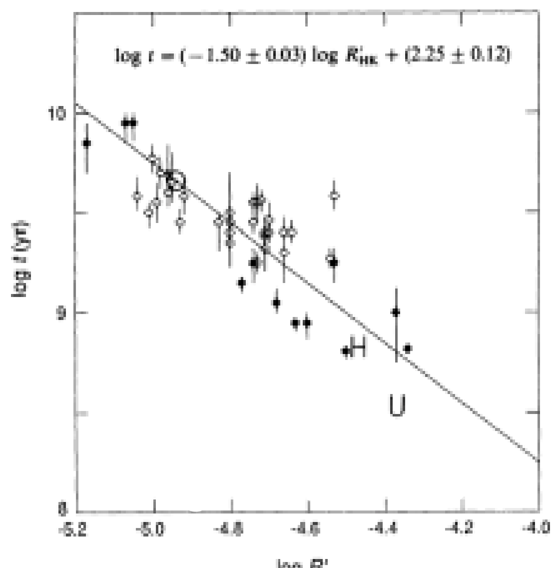
Additional Reason for Seeking Gas in Debris Disks (Roberge,Vidal-Madjar)

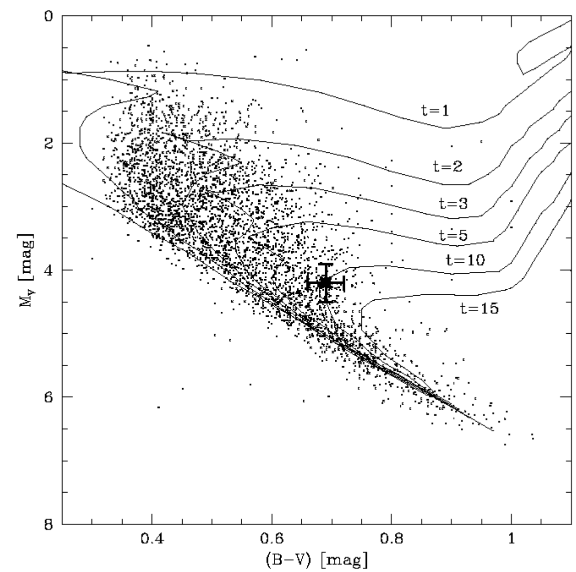
- Gas drag tends to bring dust to midplane, as do inelastic collisions. (Because of such collisions, Saturn’s rings are believed to be locally only meters thick, although its apparent edge-on thickness is of order 1 to 2 km because of bending waves excited by interaction with Mimas at the 5:3 resonance.)
- If debris disks can be shown to have non-negligible thickness then their vertical motions must be pumped up by gravitational encounters with larger bodies whose surface escape velocities are at least comparable to dust’s random velocities.

Chronometers (Eric Gaidos)

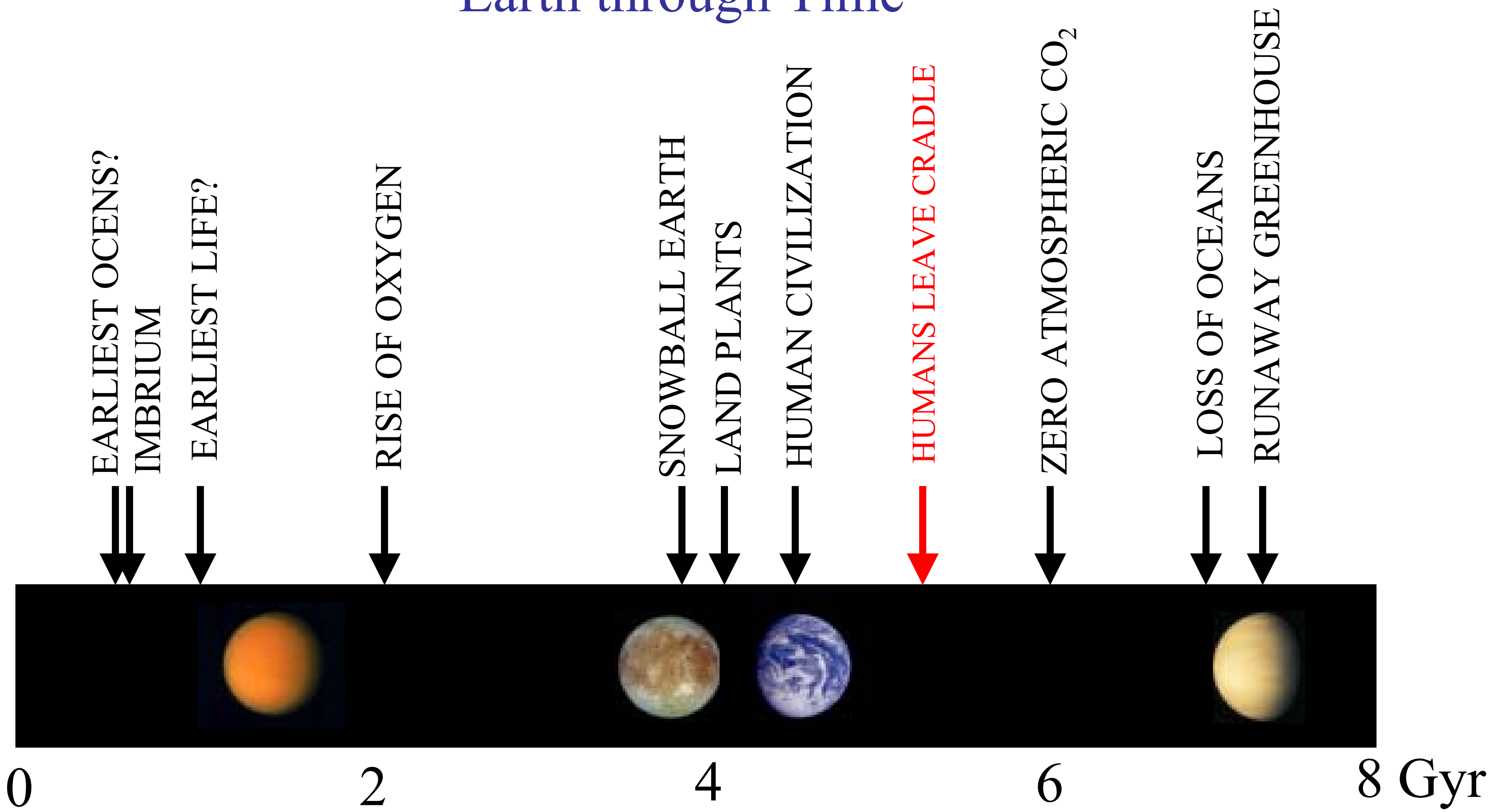








Earth through Time

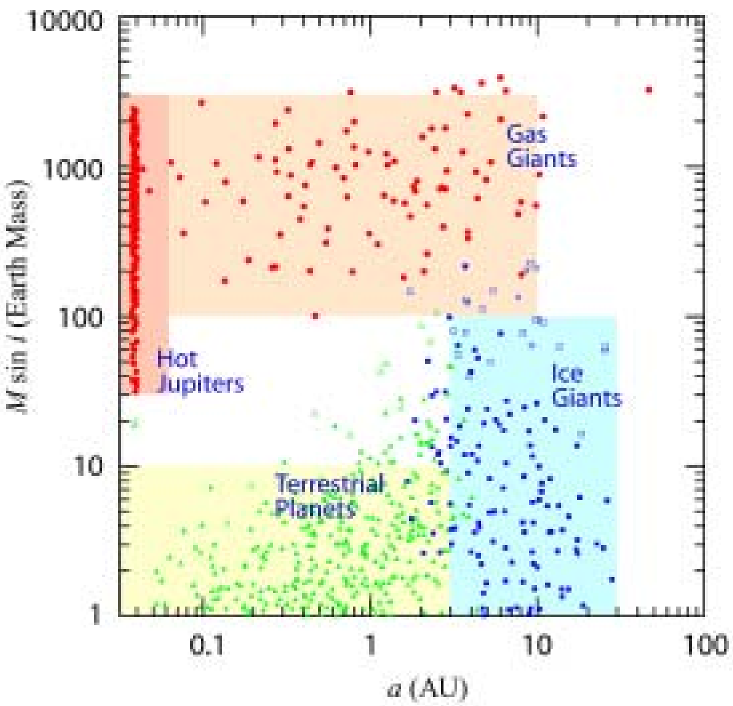


Appearance of Earth has changed (and will change) markedly over main-sequence lifetime of Sun

Eric Gaidos

Out of the Box Thinking

- Alain Leger – Water Worlds
- Kevin Zahnle – Snowballs in Hell
- Will tend to fill in the much needed gap in Doug Lin's theory.
- Should also broaden our notion of "habitable zone," which if nothing else ignores evolution of intelligent beings.
  - Terraforming
  - Dyson belts
  - Travel to other stars
- Have others done any of the above?



Lin (2003)

as cited by

Chas Beichman

Conservative & Aggressive Habitat Characterization

- For core TPF/Darwin program, it probably pays to have a rationally conservative target list (e.g., Margaret Turnbull's presentation).
- But there should be a substantive guest investigator program, where unusual targets are tried. The unanticipated findings are likely to prove the most interesting scientifically in the long run, e.g., what are planets around BDs like (Ilaria Pascucci)?
- Example of HST being justified originally to determine H_0.
- Be prepared to be pleasantly surprised.
- Thank you everyone for building the community!